DEMONSTRATION OF MAGNETRON AS AN ALTERNATIVE RF SOURCE FOR SRF ACCELERATORS*

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Abstract: Magnetron has been considered as alternate high-efficiency, low-cost RF sources for linacs and storage rings for national labs and industrial applications. After the demonstration of magnetrons power to drive and combine for a radio frequency cavity at 2450 MHz in CW mode, we have used trim coils adding to a water-cooled magnetron and amplitude modulation feedback to further suppress the sideband noise to -46.7 dBc level. We also demonstrated the phase-locking to an industrial grade cooking magnetron transmitter at 915 MHz with a 75 kW CW power delivered to a water load by using a -26.6 dBc injection signal. The sideband noise from the 3-Phase SCRs DC power supply can be reduced to -16.2 dBc level. Further noise reduction and their power combining scheme using magic-tee and cavity type combiners for higher power application (2x50kW) are to be demonstrated. We intent to use one power station to drive the normal conducting FPC, booster and superconducting RF cavities for the industrial linac.

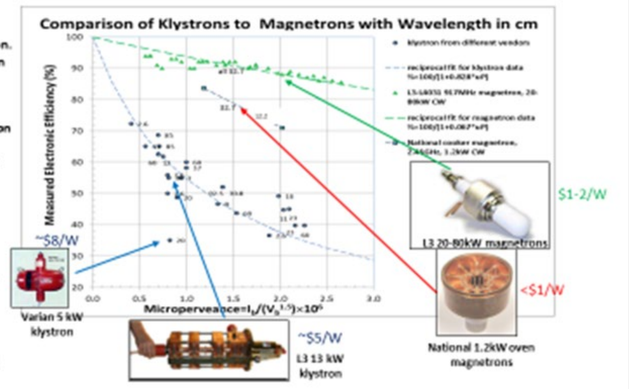
Motivation of using magnetrons as RF sources of particles accelerators

Magnetrons:
- Forms bunches in spoke-on-hub process in circular motion. Beam-to-RF cavity interaction in multiple circular passes. Much less wasted energy.

Klystrons:
- Space-charge effect in electron bunch forming process in linear motion dominates the efficiency. Spent energy deposits in the collector.

References:
- High efficiency klystrons (>80%) ? Lower perveance:
- Multi-beam (cluster)
- Long cavity interaction to do adiabatically bunching
- High efficiency SSAs?

Low frequency, <1.5GHz, <45%, $11-15/W, need more R&D for higher efficiency and lower cost

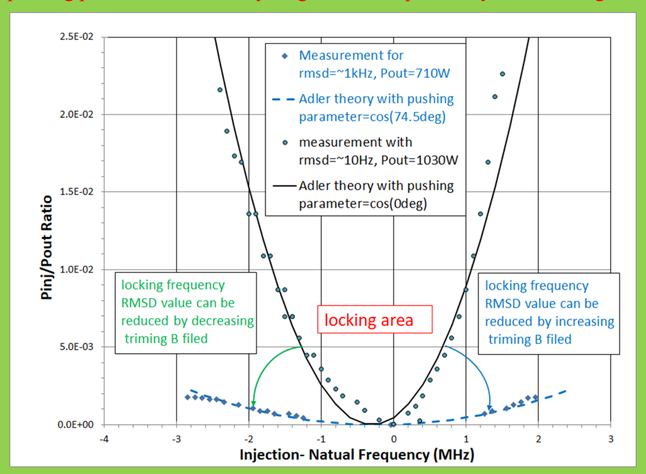


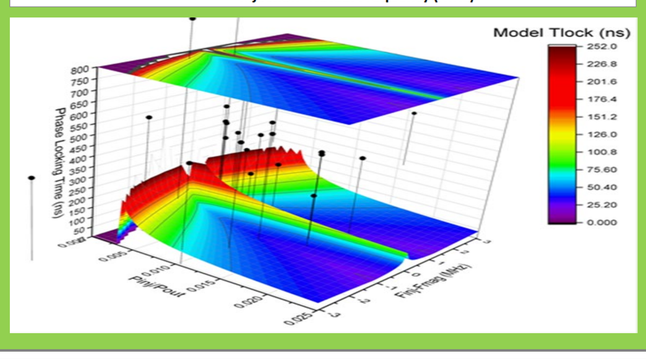
Comparison of tube efficiencies between klystrons and magnetrons with their wavelength in cm marked next to their data points

Adler/Chen Injection Phase Lock and Stability Diagram

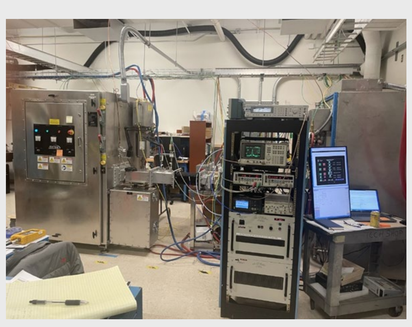
$$sin\emptyset = 2Q_L cos\alpha \sqrt{\frac{P_{out}}{P_{inj}}} \frac{\omega_0 - \omega_i}{\omega_0}$$

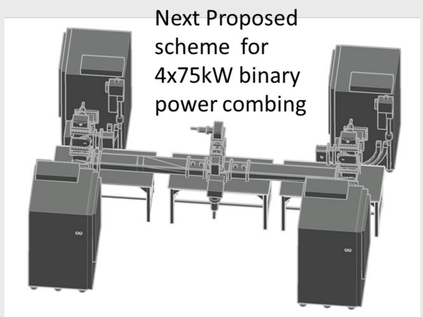
- P_{inj} is locking power
- P_{out} is output power
- Q_L is the loaded Q of magnetron
- ω_i is the frequency of injection signal
- ω_0 is instantaneous natural frequency of magnetron
- α is phase lag between electron rotating spoke and resonant RF peak called frequency pushing parameter. Its stability diagram can be pushed by external magnetic field





Future Plan for NCRF/SRF Application





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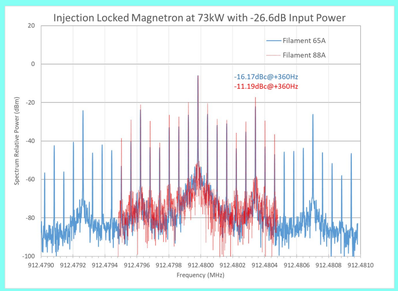
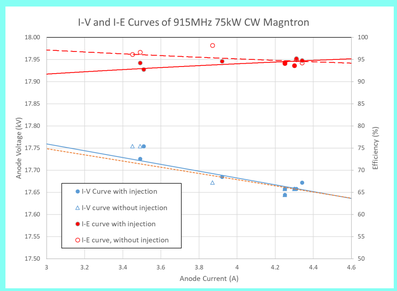
915MHz Magnetron at 75kW for Industrial Application

- High (>90%) AC to RF power efficiency
- Low (<$1/W) capital cost
- WR975 waveguide to drive accelerator components
- Demonstrated injection phase lock performance
- Demonstrated Magic-tee power combining (at 2.45GHz so far)
- 4 × 75kW is going to be installed
- Smart and low-cost switching power supplies for SRF application

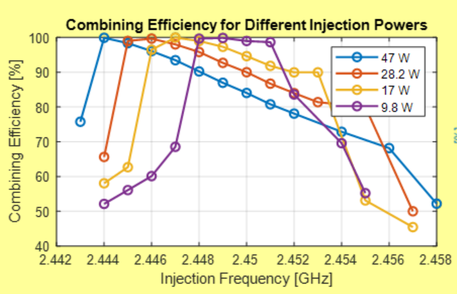
Phase Lock Performance

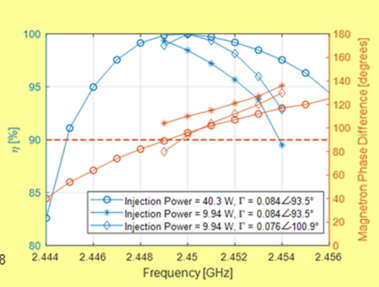


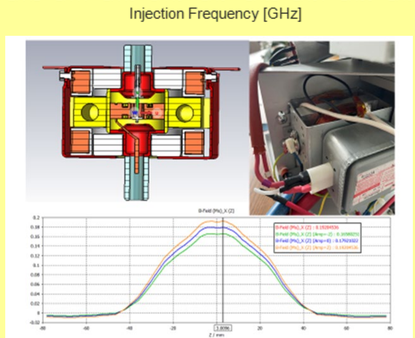


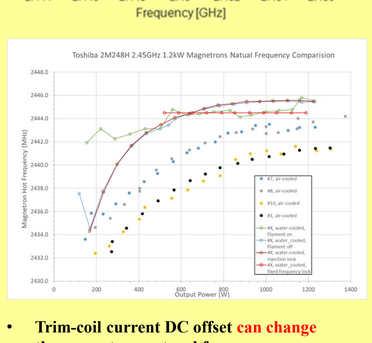
High power injection phase lock experiment at the first unit (left) on July 14, 2022 and at the second unit (right) on Dec. 16, 2022. The injection power to the first unit was 164W locked to 75kW output power (-26.6dBc).

Amplitude Modulation for Power Combining and MW Accelerator







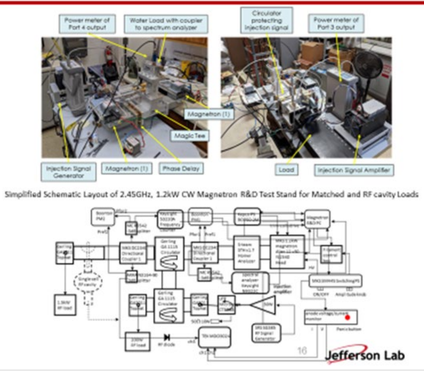


- **Trim-coil current DC offset can change the magnetron natural frequency**
- **=-5.63kHz/A*turn**
- **=-14.64uT/Aturn**

2.45GHz magnetron with trim-coil modulation feedback

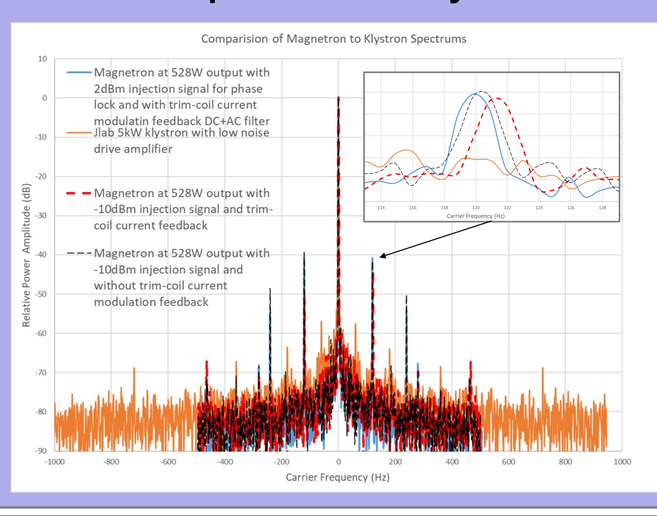
- Pickup at anode current monitor of MKS switching power supply
- Feedback by SRS SR560 Low Noise Preamplifier
- Output impedance=50Ohm
- Gain=5, HP filter=0.3Hz, LP filter=1kHz
- Using KEPCO BOP 50-2M (0 to ±50V 0 to ±2A) bipolar power supply to drive trim coils.
- Trim coil pairs has total turns of 280
- Sideband noise at 120Hz has been reduced from -34.0dBc to -40.0dBc level.
- Carrier frequency peak has been increased from -11.51dB to -11.37dB. All sideband noise of higher harmonics are gone.

JLab and GA's 2.45GHz Magnetron R&D and Power Combining Test Stands



- JLab: Switching anode power supply, single magnetron with trim-coil feedback
- GA: four magnetrons with magic-tee and cavity type power combiner
- JLab will characterize the trim-coil mounted and water-cooled magnetron heads
- GA will use magic-tee and cavity type power combiners to get 4×1kW output power
- InnoSys will develop the smart FPGA controlled power supplies for magnetrons
- We will develop injection phase lock and amplitude control algorism together

Comparison with Klystron



Conclusions

- We have demonstrated injection phase lock performance on both 75kW 915MHz magnetron transmitters
- Progress is being made on the Magic-tee power combining in both system requirement and control algorithm
- Trim-coil current modulation experiments with a fast feedback system at 2.45GHz magnetron have demonstrated a good spectrum competing to a low-noise operational klystron
- 4 x 75kW high power combining is in our next experimental proposal for the industrial application in both NC and SC RF accelerator systems.

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